United States
Environmental Protection
Agency

Hazardous Waste Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/540/S2-85/004 Jan. 1986

EPA

Project Summary

Leachate Plume Management

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A handbook was developed on the management of leachate plumes, a problem that has been somewhat aggravated by a lack of understanding of plume dynamics and the various remedial options available. The handbook describes factors that affect leachate plume movement and key considerations in delineating the current and future extent of the leachate plume. Four technologies for controlling the migration of the plume are also discussed: (1) groundwater pumping to extract water from or inject water into wells to capture a plume or alter the direction of groundwater movement; (2) subsurface drains consisting of permeable barriers designed to intercept groundwater systems; (3) vertical underground barriers made of low-permeability materials to divert groundwater flow or minimize leachate generation and plume movement; and (4) innovative technologies that biologically or chemically remove or attenuate contaminants in the subsurface.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Cleaning up the thousands of hazardous waste release sites identified across the Untied States is a serious environmental challenge to the nation. Of particular importance is protecting and treating contaminated groundwaters that now serve or could serve as drinking water supplies. Successful control of leachate plumes from uncontrolled hazardous waste sites requires a thorough understanding of plume dynamics and aquifer restoration technologies. The problem of leachate plume management has been intensified to some extent by a lack of understanding of plume dynamics and the various site remedies available. Methods for controlling the migration of a leachate plume generally fall into one of four categories—groundwater pumping, subsurface drains, low-permeability barriers, or innovative technologies.

The purpose of this project was to prepare a reference manual on the movement of hazardous leachate plumes and their management. This summary presents an overview of the manual, which consists of eight chapters:

1. Introduction,
2. Plume dynamics,
3. Plume delineation,
4. Plume control technologies,
5. Groundwater pumping,
6. Subsurface drains,
7. Low-permeability barriers, and
8. Innovative technologies

Plume Dynamics

In terms of plume movement, the simplest type of leachate plume is one that mixes with groundwater and moves with it at the same rates and in the same directions. In this case, plume velocity (ignoring attenuation and other geochemical factors) can be expressed by Darcy's Law:

$$V = K\,i/n = Ti/bn$$

where V is the velocity of the plume, K is the effective permeability or hydraulic conductivity of the aquifer, i is the hydraulic gradient, the slope of the water table, or the potentiometric (pressure) surface, n is the porosity of the aquifer, T is the transmissivity of the aquifer or its ability to transmit water to wells, and b is the saturated thickness of the aquifer through which groundwater flows.

Thus, the velocity of a plume moving with groundwater will be directly related to the transmissivity and the gradient and inversely related to the saturated thickness and the aquifer's porosity.

The direction in which simple plumes move is controlled by the gradient of the potentiometric surface. In unconfined aquifers, this gradient commonly follows the surface topography, but it can be affected by a variety of hydrologic and geologic factors, including aquifer geometry and uniformity, geologic discontinuities, and hydraulic barriers.

In addition to hydrogeologic factors, manmade alterations of surface or subsurface conditions can also affect the direction and rate of leachate plume migration. The cumulative effects of these and other factors can make predicting plume migration patterns an extremely complex task, even for water soluble plumes that move with groundwater flow. Consequently, it is imperative to delineate plumes on a site-specific basis.

Plume Delineation

Before the options for leachate plume management at a given site can be developed, the dimensions of the plume must be delineated. A variety of direct and indirect methods exist for obtaining data on plume dimensions including the following:

- Aerial image interpretation
- Hydrogeologic investigations
- Geophysical investigations
- Groundwater sampling
- Hydrologic (computer) modeling

Aerial imagery refers to pictorial representations produced by electromagnetic radiation that is emitted or reflected from the earth and recorded by aircraft-mounted sensors.

A hydrogeologic site investigation typically consists of installing a number of wells and conducting tests which characterize the ability of the aquifer to store and transmit water. Information on site geology and pedology, leachate seeps, geologic discontinuities, and discharge and recharge barriers are required.

A geophysical survey can provide a cost effective way of collecting data on subsurface geology, especially when the geology of the site is highly variable. The geophysical methods most commonly used in site investigations are resistivity, seismic, metal detection, and radar. Properly applied geophysical survey methods can determine the lateral and vertical extent of the plume, approximate changes in contamination with depth, establish depth of bedrock, and locate metal drums or debris.

The most direct means of delineating a leachate plume is by groundwater sampling. Typically, the wells installed during the hydrogeologic investigation are also used for obtaining samples of the contaminated groundwater. However, obtaining valid groundwater data is extremely difficult because of the large number of variables involved. The results of the chemical analyses of these samples can be plotted on a site map and contoured in much the same way as water tables and land surface elevations. These maps can then be used to determine the direction of plume movement.

Computer models of groundwater have been used to evaluate the extent and expected movement of plumes. Two categories exist for groundwater models: analytical models, which use simplified, explicit expressions generated from partial differential equations, and numerical models, which reduce partial differential equations to a set of algebraic equations that are solved through linear algebra. Both types of models can evaluate plume movement in three dimensions.

Plume Control Technologies

Selection and Evaluation

Identifying the most appropriate technique for managing a leachate plume can be extremely complex. The selection process involves the acquisition, evaluation, and application of data that vary in reliability, applicability, and depth of detail. Though data development is relatively straightforward, the evaluation and use of the data can be difficult because of the many interrelated elements. Furthermore, developing and evaluating plans for site-specific remedies requires a great deal of technical judgment. Basically, four plume management technologies are available—well systems, subsurface drainage systems, subsurface barriers, and in situ treatment techniques. Variations and combinations of these technologies can result in many possible plume management alternatives, however.

Once the technologies and their required auxiliary measures have been identified and developed into a site restoration alternative, a preliminary evaluation can be initiated for each alternative. This screening step involves assessing the suitability of each alternative relative to specific site conditions.

After the problems with a site have been assessed and priorities have been set for mitigating them, specific response goals can be established. These can be stated in specific or general terms. Establishing goals before the technology screening and detailed analysis steps is extremely important to focus control efforts on the most critical problems of the site.

The cost evaluation involves comparing the costs of alternatives that produce similar environmental, public health, and public welfare benefits.

Groundwater Pumping

Pumping technologies have been shown to be most effective for plume management at sites where underlying aquifers have high intrinsic permeabilities (e.g., coarse-grained sands) and where the contaminants move readily with groundwater (e.g. benzene). Pumping methods have also been used with some effectiveness at sites where pollutant movement is occurring along fractured or jointed bedrock. Note, however, that the fracture patterns must be traced in detail to ensure proper well placement.

Well systems can be designed to perform several functions with or without the assistance of other technologies (e.g., barrier walls). The main applications in plume management are groundwater level adjustment, plume containment, and plume removal.

Groundwater levels can be adjusted by using extraction wells to lower water levels or injection wells to create groundwater mounds or barriers. By adjusting groundwater levels, plume development can be stopped at the source, or the speed and direction of the plume can be altered. In either case, contaminated water is not extracted from the groundwater system as it is with containment and removal techniques.

A well system used to contain a plume may incorporate extraction wells or a combination of extraction and injection wells. Containment differs from removal in that the source of contamination is not generally stopped, so contamination is an ongoing process. Because containment requires removing contaminated groundwater, a treatment or disposal method must be developed to handle the discharge from the system.

Plume removal implies a complete purging of the groundwater system to remove contaminants. Removal techniques are suitable when contaminant sources have been stopped (e.g., by waste removal or site capping) or contained (e.g., by barrier walls) and aquifer restoration is desired. Extraction wells or extraction and injection well systems can be used in plume removal. Numerous arrays and patterns are available for injection and extraction wells, and the choice usually depends on suitability for a specific job. Extraction and injection techniques can also be used with flushing compounds to accelerate contaminant removal. As with containment designs, treatment of pumped water is necessary.

Subsurface Drains

Subsurface drains include any type of buried conduit used to collect liquid discharges (i.e., contaminated groundwater) by gravity flow. The major components of a subsurface drainage system include drain pipes, envelope or filter or both, backfill, manholes or wetwells, and pumping stations.

Subsurface drains function like an infinite line of extraction wells. That is, they form a continuous zone of depression that runs the length of the drainage trench.

Functionally, two basic types of drains exist—relief drains and interceptor drains. Relief drains are installed in areas where the hydraulic gradient is relatively flat. They are generally used to lower the water table beneath a site or to prevent contamination from reaching a deeper underlying aquifer. Relief drains are installed in parallel on either side of the site so that their areas of influence overlap and contaminated groundwater does not flow between the drain lines. They can also be installed completely around the perimeter of the site.

Interceptor drains, on the other hand, are used to collect groundwater from an upgradient source to prevent leachate from reaching wells or surface water located hydraulically downgradient from the site. They are installed perpendicular to groundwater flow. A single interceptor at the toe of a landfill or two or more parallel interceptors may be needed, depending on the circumstances.

Whether a drain functions like an interceptor or a relief drain is determined by the hydraulic gradient. The design of these drain types differs, but construction and installation are the same.

Though subsurface drains perform many of the same functions as pumping systems, drains may be more cost effective under some circumstances. For example, they may be particularly well suited to sites with relatively low permeability where the cost of pumping may be prohibitively high because wells need to be spaced very closely.

A number of limitations exist on the use of subsurface drains as a remedial technique. They are not well suited to areas of high permeability and high flow rate. Also, contamination at great depth may cause prohibitive construction costs, particularly if a substantial amount of hard rock must be excavated. Subsurface drains are also unsuitable for viscous or reactive plumes, since such leachate may clog the drian systems.

Low-Permeability Barriers

Low-permeability barriers can be used to divert groundwater flow from a waste disposal site or to contain contaminated groundwater leaking from a waste site. Three major types of low-permeability barriers are applicable to leachate plume management—slurry walls, diaphragm walls, and grout curtains.

Slurry Walls

A slurry wall is a subsurface barrier consisting of an excavated trench that uses a bentonite and water slurry to support the sides. The trench is then backfilled with materials of far lower permeability than the surrounding soils. The slurry backfill trench or slurry wall reduces or redirects the flow of groundwater.

Slurry walls include two major types of barrier walls—soil-bentonite and soil-cement walls. Soil-bentonite walls are composed of soil (often trench spoils) mixed with small amounts of the bentonite slurry from the trench. Cement-bentonite walls are made of a slurry of Portland cement and bentonite.

Soil-bentonite walls generally have the lowest permeability, the widest range of waste compatibilities, and the lowest cost. They also offer the least structural strength (highest elasticity), usually require the largest work area, and are restricted to a relatively flat topography unless the site can be terraced.

Cement-bentonite walls can be installed at sites where there is insufficient work area to mix and place soil-bentonite backfill. These walls can be installed in a more extreme topography if wall sections are allowed to harden and the wall is continued at a higher or lower elevation. Although cement-bentonite walls are stronger than soil-bentonite walls, they are at least an order of magnitude more permeable, resistant to fewer chemicals, and more costly.

Diaphragm Walls

Diaphragm walls are one of the three major types of barrier walls used (along with soil-bentonite and cement-bentonite walls). A diaphragm wall is a subsurface barrier designed for structural strength and integrity in addition to low permeability. Diaphragm walls can be made of cast-in-place concrete or precast panels with cast-in-place joints.

Diaphragm walls are the strongest of the three types of barrier walls as well as the most costly. If the joints between panels are installed correctly, diaphragm walls have approximately the same permeability as cement-bentonite walls, and because the materials are similar, about the same chemical compatibilities. Diaphragm walls are most typically used in situations requiring structural strength and relatively low permeability.

Grout Curtains

A grout curtain is a subsurface barrier formed through the pressure injection of one of several special grouts into a rock or soil body to seal and strengthen it. Once in place, these grouts set or gel into the rock or soil voids, greatly reducing soil permeability and imparting increased mechanical strength to the grouted mass. This process results in a grout wall or curtain. Because a grout curtain can be three times as costly as a slurry wall, it is rarely used when groundwater has to be controlled in soil or loose overburden. Grout is used primarily to seal voids in porous or fractured rock when other methods of controlling groundwater are impractical.

Four basic techniques exist for installing a grout curtain:

- Stage-up method
- Stage-down method
- Grout-port method
- Vibrating-beam method

As with slurry walls, placing a grout curtain upgradient from a waste site can redirect the flow so that groundwater no longer contacts the wastes that are creating the leachate plume. However, placement of a grout curtain downgradient from a hazardous waste site may not be successful because of grout/leachate interactions. For example, the grout setting time is often hard to control, thus making it difficult to emplace a curtain of reliable integrity. Additional problems can occur when attempting to grout a horizontal curtain or layer beneath a waste site. In such cases, injection holes must be drilled either directionally from the site perimeter or directly through the wastes.

Innovative Technologies

Leachate plumes may be treated in place by certain biological and chemical treatments that are specifically designed to remove plume contaminants. Contaminated plumes consisting chiefly of biodegradable organics may be treated by in-place bioreclamation (biodegradation). Chemicals may also be injected into the leachate plume to neutralize, stabilize, or mobilize contaminants. For example, soil flushing is used as an in situ technique to flush residual contaminants from soil particles to mobilize them for collection and treatment. Usually water is the flushing medium, but dilute solutions of surfactants and organic solvents have also been proposed.

Bioreclamation

Bioreclamation is an in situ groundwater treatment that uses a combination of microorganisms, aeration, and the addition of nutrients to accelerate the biodegradation rate of groundwater contaminants.

Many species of bacteria, actinomycetes, and fungi have been found to degrade hydrocarbons associated with petroleum. Bacteria are the prime microorganisms involved with the biodegradation of petroleum and other organics in groundwater. Naturally occurring species of the genera *Pseudomonas, Arthrobacter, Nocardia Achromobacterium,* and *Flavobacterium* have been found to attack petroleum hydrocarbons and other organic chemicals. With the addition of nutrients and oxygen, these bacteria can be stimulated to develop a population that is adapted to readily degrade organic chemicals present in groundwater.

An alternative to developing adapted populations from naturally occurring bacteria is to inoculate the subsurface with mutant microorganisms developed in the laboratory to degrade specific organic chemicals or chemical groups. This alternative is advantageous because it may increase overall biodegradation rates of specific organics and it eliminates the time required for adaptation of a naturally occurring population.

The selection of bioreclamation as a plume management technique depends on the biodegradability of the components in the contaminant plume. Biodegradabilities of various organic substances are based on the ratio of biochemical oxygen demand (BOD) to chemical oxygen demand (COD). Compounds are considered relatively undegradable if their BOD/COD ratio is less than 0.01, moderately degradable if their ratio is 0.01 to 0.1, and degradable if their ratio is 0.1 or greater.

Implementation of the bioreclamation process involves placing extraction wells to control migration of the contaminant plume by pumping. Groundwater pumped to the surface is mixed with nutrients and reinjected upgradient of the extraction wells. Specialized mutant bacteria may also be added along with the nutrients. The groundwater may be oxygenated with air, oxygen, or hydrogen peroxide.

Bioreclamation has been used successfully in many cases to treat contaminated groundwater plumes from underground gasoline and hydrocarbon leaks. The technique has not yet been demonstrated for groundwater treatment at uncontrolled hazardous waste disposal sites, but its potential for treating hydrocarbon-contaminated groundwater establishes it as a viable technique.

In Situ Chemical Treatment

In situ chemical treatment techniques involve the injection of a chemical into a leachate plume to neutralize, detoxify, precipitate, or otherwise affect the contaminant materials. These techniques are highly dependent on the contaminant and have in the past been used only for spills of specific chemicals. Dilute solutions of acids or bases such as nitric acid or sodium hydroxide could theoretically be used to neutralize acidic or basic groundwater contaminants. A system of extraction and injection wells could be used to disperse the neutralizing agent and to contain and cycle groundwater until the appropriate pH was attained. Other chemical agents could also be used in this manner to detoxify plume contaminants. Sodium hypochlorite, for instance, has been used to oxidize cyanide-contaminated groundwaters. Other oxidizing chemicals such as hydrogen peroxide and ozone may be applicable to this type of remedial approach. Solutions of sodium sulfide have also been proposed to precipitate toxic metals from groundwater and thereby immobilize them. Recently, an underground spill of acrylate monomer was attenuated by the injection of a catalyst that caused the contaminant plume to polymerize and solidify.

Block Displacement

Block displacement is a technique developed for completely isolating a large mass of contaminated soil. The concept relies on producing a fixed underground barrier around and beneath the contaminated zone to encapsulate a block of earth. The method involves construction of a perimeter and a bottom barrier that are interconnected to allow block displacement.

The block displacement method was developed for application where an unweathered bedrock or impermeable stratum below a contaminated zone is not shallow enough for a perimeter (e.g., slurry wall) alone to provide cost-effective isolation of the contaminant plume. In situ isolation using a slurry wall or other conventional vertical barriers requires keying the barriers into a naturally occurring impermeable stratum. Block displacement is also designed to minimize the volume of soil or earth to be isolated. Thus block displacement would theoretically isolate a contaminated area through the creation of a man-made confining layer immediately surrounding the contaminated zone.

Problems associated with block displacement include (1) difficulties in ensuring bottom barrier continuity, (2) health and safety, and (3) environmental and construction risks of drilling injection holes through a contaminated zone and potentially through hazardous materials. Even if injection holes could be constructed safely, they could potentially serve as conduits for increased rates of vertical contaminant migration before slurry injection.

The full report was submitted in fulfillment of Contract No. 68-03-3113 by JRB Associates under the sponsorship of the U.S. Environmental Protection Agency.

☆U. S. GOVERNMENT PRINTING OFFICE:1986/646-116/20745

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The complete report, entitled "Leachate Plume Management," (Order No. PB 86-122 330/AS; Cost: $46.95, subject to change) will be available only from:
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